A Biogeochemical Model of Link Lake

1. Overview

Quantitative biogeochemical modelling is part of an overall effort to provide an integrated description of ecological systems within the framework of ecological engineering. It is a tool which can aid engineers and managers to simulate environmental remediation strategies, and which can provide an understanding of the dynamics of an ecosystem.

The Rabbit Lake drainage basin will change with time with respect to contaminant and nutrient loading. The reason for the changes are the depletion of nutrient supply from the waste rock piles and the addition surface water flow from the decommissioned Rabbit Lake pit. These changes will affect the successional changes in the aquatic vegetation dominating the drainage basin. The aquatic vegetation control water quality in retaining both nutrients and contaminants within the drainage basin and through discharge.

In planning best decommissioning options for the drainage basin it is necessary to integrate, optimize and engineer the natural ecological processes which will take place. If the natural changes which will take place are not defined, control of contaminant discharge from the basin is not possible.

In order to understand these changes the main biogeochemical cycles in the Rabbit lake drainage basin are outlined based on the information the drainage basin gained during the study of the contaminant and nutrient cycling in Upper and Lower Link Lake.

A biogeochemical model which is proposed to be developed aims to integrate all of the important biogeochemical cycles into a dynamic description capable of predicting concentrations of contaminants, other species, nutrients and algae.

2. Growth and Nutrient Dynamics in Link Lake

Link Lake is eutrophic due to the nutrient loading originating from the waste rock piles in the upper part of the Rabbit Lake Drainage Basin. This can be both an advantage and disadvantage with respect to biologically based remediation of Ra^{226} and U contamination within Link Lake. The advantage is that algae is expected to thrive in this nutrient rich environment. The problem is that several species thrive and compete for resources, whereas only one is best able to remove Ra^{226}. The three principal algae are phytoplankton, periphyton and *Nitella* (a Characean algae). *Nitella* best removes the radioactive contaminants, but the other algae, especially the phytoplankton, can grow in this nutrient rich environment to the extent that *Nitella* growth is inhibited. The buildup of large amounts of dead plant on the sediment can lead to the production of ammonium, an occurrence which is especially deleterious to *Nitella* regenerating through oospore.

To achieve the optimum crop of *Nitella*, therefore, requires a clear understanding of growth and nutrient cycling within Link Lake. The nutrients, mainly nitrates from explosive residuals in the waste rock pile, are removed from water passing through Upper Link Lake likely due to two overall processes:

a) Assimilatory nitrate reduction, the direct uptake of nitrate by vascular plants and by phytoplankton, periphyton and *Nitella* populations in Upper Link Lake.

b) Denitrification and dissimilatory nitrate reduction in anaerobic sediments of Upper Link Lake, Delta and surrounding muskeg.

In the case of a) nitrate is not removed from the ecosystem but rather incorporated within the cells of plants and algae. When the plants die and settle to the bottom the decomposing biomass releases the nitrogen in a process termed ammonification. $NH4^+$ in high concentrations is proposed to be toxic to germinating *Nitella* oospore, and thereby inhibiting regeneration of the population. Dissimilatory nitrate reduction also recycles nitrogen within the ecosystem, again in the form of $NH4^+$.

The Existing Biological Polishing Model:

Through a postdoctoral fellowship a biological polishing model has been developed over the over the last two years to predict changes in the contaminant removal of the biological polishing process. As nutrients affect the production of algae, which are relevant in the process to collect precipitates part of this model integrates changes in nutrient concentrations.

As an example of the sort of output a biogeochemical model can be expected to produce,
a simple growth and nutrient model has been constructed. The model was run using input data drawn from the Boojum database of Link Lake. The resulting output is the concentration of $NO3^-$ in the water column, the concentration of $NH4^+$ in the pore water, and the density of algae on the lake bottom. An examination of the plotted results reveals the general picture: $NO3^-$ is taken up by algae as it grows (therefore, the decrease of $NO3^-$ in the water column), $NH4^+$ is released from the decaying plant biomass in the sediment (a large increase in NH4+ in the pore water), and algal growth appears to be inhibited by high concentration of $NH4^+$ in the pore water.

In general, the existing model produces curves, which indicate the correct trends of the interactions of the biological processes. It should be noted, that of course algal biomass is not alone controlled by ammonia and only regenerating biomass is proposed to be affected.
Nevertheless, the model at present has the basic components which can be utilized and through modification adapted to address the Rabbit Lake drainage basin.

The required changes and adaptations to the existing biol polishing model are outlined in Milestone form below.

Adsorption of Ra^{226} and U in Link Lake

Nutrient cycling within Link Lake is part of the overall biogeochemical cycles in the system. In addition to nutrient loading, Link Lake receives Ra^{226}, U and several other elements as the result of weathering. The main objective is to remove Ra^{226} and U from the waste water. This is quantified through an adsorption submodel which includes both bioadsorption on algae, and adsorption and desorption to and from sediments respectively.

Boojum Research has to date developed a biogeochemical model of biological polishing in the case of heavy metal contamination. In this model, aqueous metal species are adsorbed by periphyton and then cycled to the sediment. The model is dynamic in that it can predict the value of several variables over a selected period of time, taking into account hydrological and other external environmental conditions. We propose to modify this model so that it can be applied to Link Lake. This entails the following changes and additions:

(i) modify the periphyton metal adsorption submodel to the case of Ra^{226} and U adsorption on phytoplankton, periphyton and *Nitella* rather than Zn.
(ii) develop a quantitative submodel of nutrient cycling.

(iii) develop a submodel of multi-species algal competition; namely, a model of interacting phytoplankton, periphyton and *Nitella* populations.

Milestones:

Milestone 1. Develop a submodel of algal growth and competition between phytoplankton, periphyton and *Nitella*.

A periphyton growth model already exists, but not a phytoplankton or *Nitella* growth model. The first step is to review the literature and Boojum database, and to develop a conceptual growth submodel. The next step is to incorporate this into the existing periphyton growth model.

Milestone 2. Develop a quantitative submodel of nutrient cycling.

The first stage is to develop a conceptual submodel of nutrient cycling in Link Lake. Extensive work has already been carried out for the relevant nutrients in the form of literature reviews determining rates of nitrogen cycling and measurements have been made specific to the Link Lake drainage basin. Thus site specific information exists in the Boojum/ Cameco data base. Once a good conceptual submodel is settled on, a quantitative submodel will be built based on it. This involves developing quantitative expressions for physical transport, and biogeochemical cycling in Link Lake.

Milestone 3. Modifying existing biological model to account for Ra^{226} and U adsorption.
This entails changing the adsorption expression in the bioadsorption submodel and enlarging the geochemical database to include Ra^{226}. Furthermore, adsorption/desorption of nutrients and contaminants in the sediment must be reformulated.

Milstone 4. Assemble the submodels.

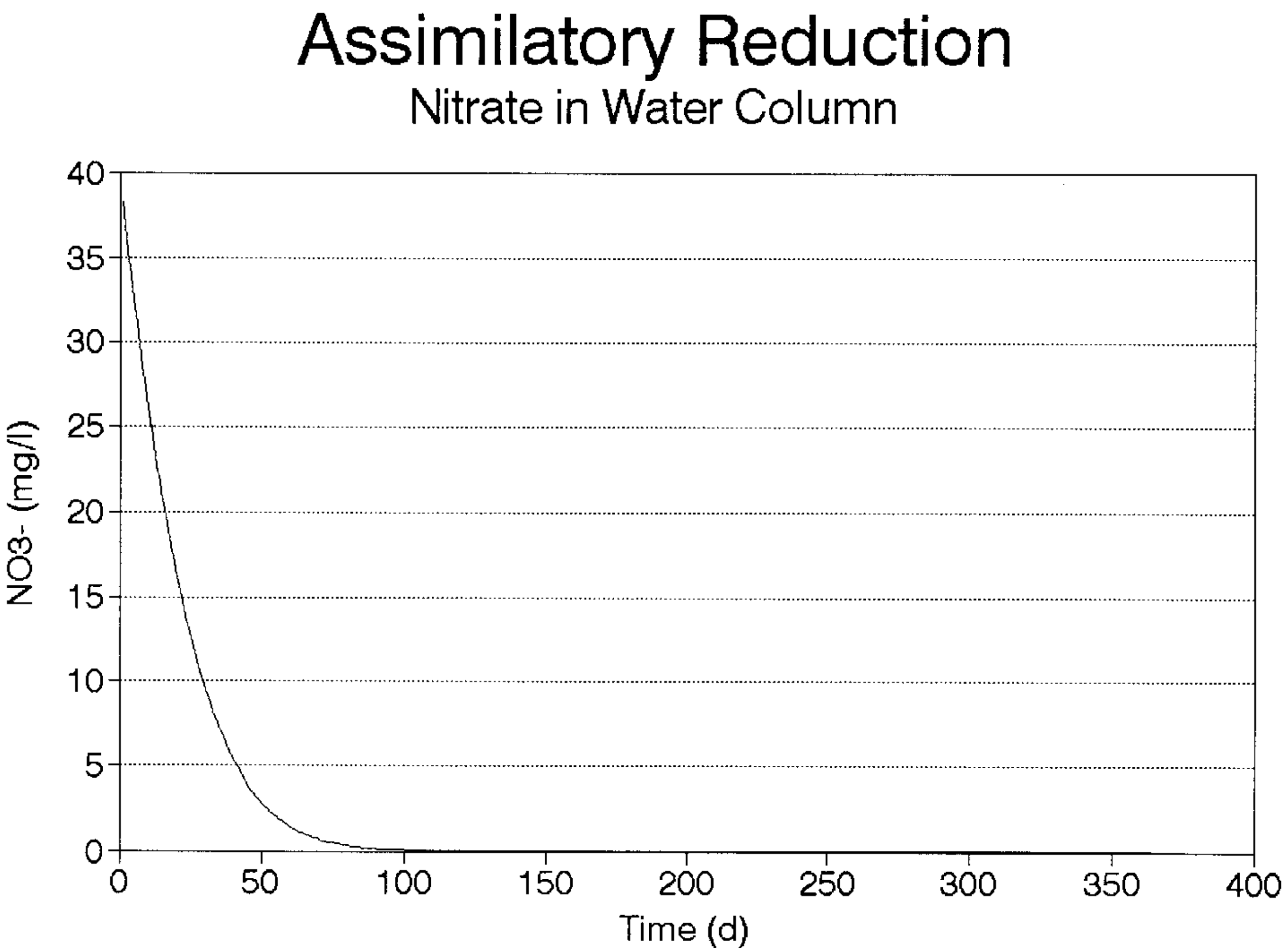
Once the submodels are calibrated and tested, they will be assembled into a single model---the resulting biogeochemical model of Link Lake. The biogeochemical Link Lake model will then be calibrated and tested further. At this point it would be ready to apply to the site.

Integrating wetland construction

Once the model for Link lake has been calibrated with real
The biogeochemical model described in the proposal can also be modified to be applicable to modelling the flow of wastewater through a wetland. Because similar nutrient cycling and contaminant adsorption operates in wetlands, many of the basic building blocks can be carried over to a wetland model. If wetlands are to be constructed in strategic locations in the Rabbit Lake Drainage Basin, a wetland model would be very useful. Therefore, we propose to adapt the biogeochemical model of Link Lake to a biogeochemical wetland model.

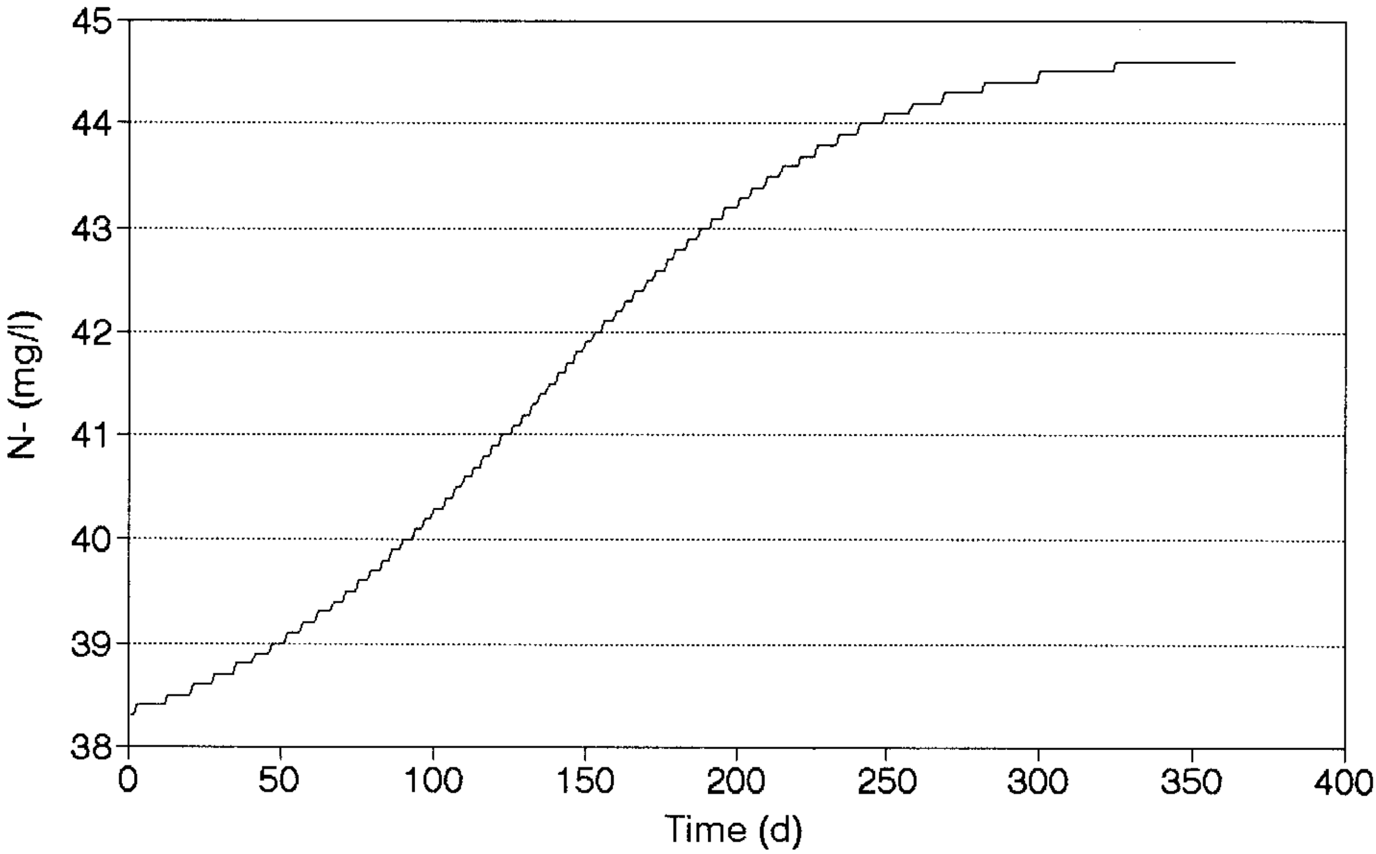
Milestone 5. Modify Link Lake model.

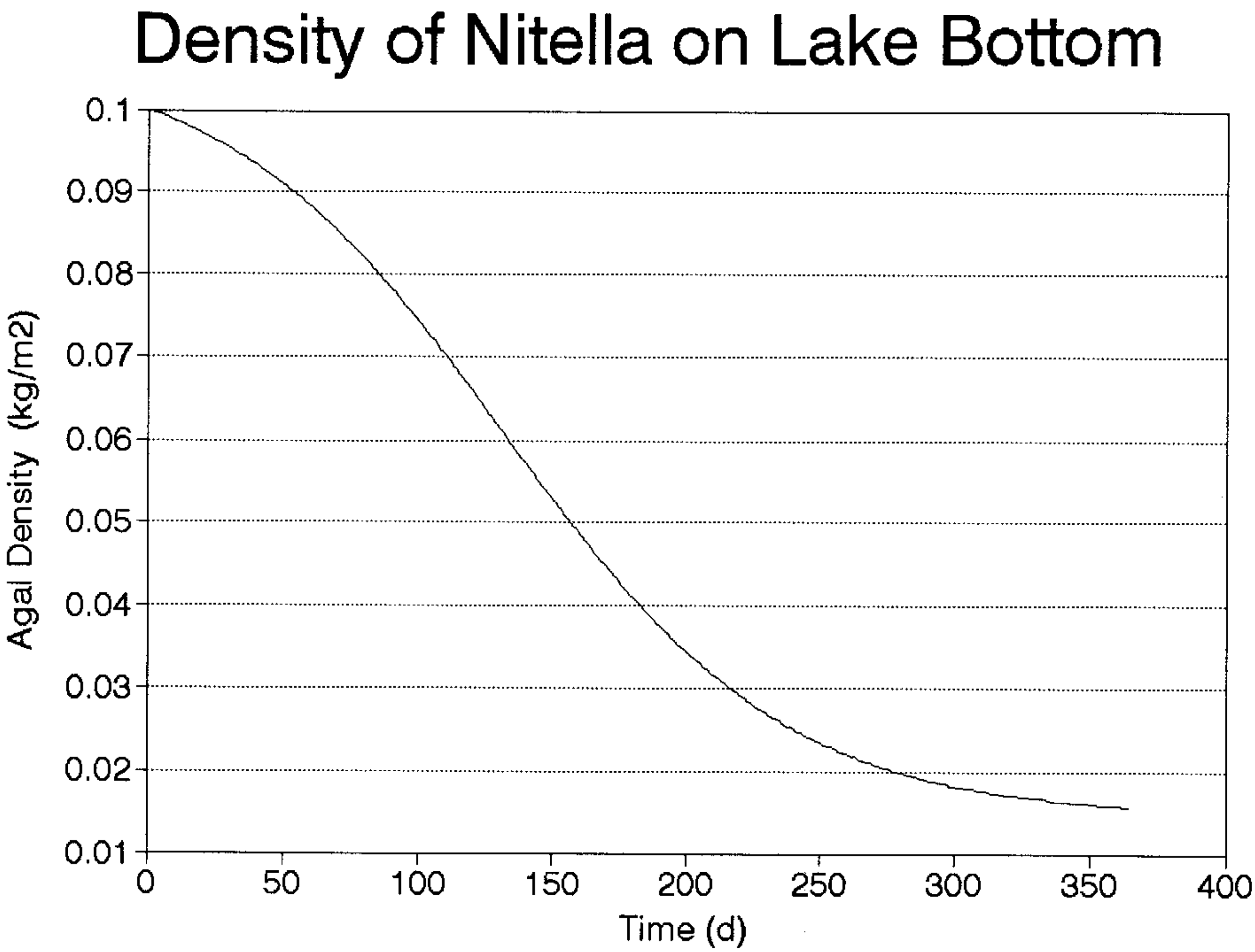
Based upon the biogeochemical model of Link Lake for which the data are available to calibrate (verify) the model, wetland models are constructed, using for example cattails, sedges etc in stead of submerged aquatic vegetation, a wetland model can be constructed.
The main modification will be the growth model. Rather than three competing algal species (phytoplankton, periphyton and *Nitella*) the modeled wetland will consist of cattails. However the basic units are similar, for example the expressions for growth.


Assimilatory Reduction
Nitrate in Water Column
NO3- (mg/l)
0
5
10
15
20
25
30
35
40
Time (d)
0
50
100
150
200
250
300
350
400

Dissimilatory Reduction/Ammonification

Production of NH4 in Pore Water




Density of Nitella on Lake Bottom
Agal Density (kg/m2)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
50
100
150
200
250
300
350
400
Time (d)